PRT Spidernet around rail hub for local empowerment of urban passenger transit: from conceptual design to simulation-based assessment methodology, with application to St Denis station of Grand Paris Express

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Abstract

The Spidernet concept consists in making a metropolitan, heavy rail station the hub of a web of elevated guided ways dedicated to small-size cabins driven automatically. Thus, comfortable point-to-point transport service would be provided to passengers, offering both speed and reliability (since its running would be uninterrupted), together with quick access and short wait at egress station were there sufficiently many "podcars". This specific concept of Personal Rapid Transit (PRT) is purported to empower the local attraction of the heavy network and to develop the hub potential as service centre and urban centre. The paper investigates these issues in the case of the St Denis station in the Grand Paris Express network by the time horizon of implementation. After introducing the territorial context and putting forward a tentative scheme of Spidernet dedicated ways and stations, we turn to simulation to study potential demand, multimodal effects, fare sensitivity and potential revenues, as well as capital and operational costs. Two models are used complementarily: first, a macroscopic, four-step Travel Demand Model at the regional level; then, PRTSim is used for microscopic traffic simulation of both passengers and podcars. Microsimulation is essential to infer realistic enough traffic conditions on the supply side (way capacity, fleet size) as well as on the demand side (effective quality of service, wait time at access station, opportunity of car-sharing). The tentative estimation of revenues and costs suggests that financial profitability might be achieved. Yet a number of important topics still deserve further investigation.

Keywords

PRT; Travel demand; Microscopic traffic simulation; Technical-economic analysis.

1. INTRODUCTION

1.1 Background

"Personal Rapid Transit" (PRT) systems now exist in a couple of places across the world: the "ancient", rail-based system in Morgantown (West Virginia) that was opened in 1975, and also some quite recent, roadway-based systems in Suncheon (South Korea), Heathrow airport (UK) and Masdar city (UAE). The basic principle is to offer point to point service with no intermediate stop, owing to dedicated ways, cabins of small size (typically from 4 to 8 places, called "podcars") driven automatically, made available on demand in short time at dedicated stations. The resulting service offers good availability in time, relatively high point to point speed, good in-vehicle comfort, together with high reliability: bundling these key features together yields fairly ideal quality of service for passenger transportation in the urban setting.

Yet only a small number of systems do exist, although more than one hundred of projects have been proposed in a variety of countries. A major reason is that most projects are purported to cover a wide urban area so as to supply many people with high quality of service and, hopefully, high benefits. But such large projects would require large investment, comprehensive urban integration and strong support from local politicians – probably up to political leadership by a local "PRT champion".

In our opinion, smaller projects, restricted to specific urban areas focused on one railway station, would be easier to implement, while still able to attract sufficient patronage so as to achieve financial profitability or at least socioeconomic profitability.

1.2 Stakes and issues

Let us focus on the concept of a PRT system, called a Spidernet® since it would make some kind of spider web around a large station of urban / suburban rail in a metropolitan context. The core function of such a system would be to attract passengers in connection to the railway line(s) serving the station. Andreasson et al. (2016) showed that such a solution would provide much added value compared to traditional station feeding by bus lines and private vehicles, on assuming a target commercial speed of 50 km/h from point to point, which would

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be definitely superior to those of traditional feeder modes, by a factor of 2 to 4. That performance would empower the attraction of the railway station by far, thus solving the "last mile(s) issue" at 1, 2, 3… km.

This emphasizes the primary Spidernet benefit of attracting more patronage to the transit system. Modal diversion, notably from the private car, would add environmental benefits. Furthermore, let us take a perspective of Transit Oriented Development (TOD): by locating more urban amenities very close to the station, then it can grow as a service centre with many functions; empowered attraction will allow to add more services, together with more clients including not only rail users but also residents in the enlarged catchment area, thus facilitating the local growth of an urban centre.

From an early experiment of shared cars system in France, namely the Praxitele project implemented in 1997-1999 near of Versailles in the south-west part of greater Paris, it came out that 3 out of 4 trips using that mode were for connection to the local railway station, and that the next demanded destinations were commercial facilities (Massot, 2000, Blosseville *et al.*, 2000). This is in favour of integrating local urban development and local solution of first class transportation and accessibility.

1.3 Objective

The paper objective is to investigate the potential benefits of such PRT spidernet around an urban railway station, from the above qualitative statement up to quantitative assessment in terms of passenger trips carried by the spidernet and additional passenger trips attracted to the railway system. These indicators stand for the primary impacts of the spidernet: they will be related to the spidernet requirements in terms of podcar fleet, specific stations, dedicated ways and associated infrastructure.

Of course, territorial setting is the key factor of system performance in these respects: this involves the metropolitan area and the passenger flows carried by the rail network, as well as local land use and urban intensity. The urban integration of a PRT mode and the financial balance of costs and revenues, though also of paramount importance, are left aside from the present study, save for some indications. As study case, we consider the St Denis node in the Grand Paris Express network, which will connect four new lines of heavy automated metro to an existing line of suburban rail in the central area of greater Paris by the 2030 time horizon.

1.4 Method

We will use two models for traffic simulation in order to investigate the patronage of the St Denis spidernet and to estimate the podcar fleet that is required accordingly (also depending on the target wait time for PRT access). The web of PRT stations and dedicated ways is postulated on the basis of territorial inspection. The sensitivity of spidernet demand to its tariff will be analysed specifically.

The first model is a macroscopic, four-step travel demand model of the whole regional area. The PRT mode is modelled as a transit sub-mode; its patronage stems from its specific usage within the multimodal transit network, mostly in the traffic assignment step, yet with feedback from assignment to mode choice and trip distribution.

The second model, PRTSim, is a microscopic traffic simulation model purportedly developed to simulate PRT traffic and operations (Andreasson et al., 2000s). Given the PRT network and the trip matrix obtained from the first model, it enabled us to derive the podcar fleet and the effective quality of service delivered by the PRT mode to its users under "realistic" traffic conditions.

1.5 Structure

The rest of the paper is in four parts. First, we introduce the study case of St Denis area in greater Paris, including our design of a particular spidernet (Section 2). Then, we model travel demand in relation to multimodal transportation supply over the regional area, in order to forecast PRT demand as a matrix of trip flows and the related local flows along the spidernet at morning peak period of workdays (Section 3). Then, using PRTsim we simulate modal operations to serve that demand and determine the size of the podcar fleet (Section 4). Lastly, we conclude by summarizing the findings and pointing to several directions for further research (Section 5).

2. TERRITORIAL CASE OF ST DENIS AREA, WITH SPIDERNET DESIGN

2.1 Greater Paris as a metropolitan region

As of 2015, the urbanized area of greater Paris is stretched over about 1,280 km² and gathers some 11 M inhabitants with 5 M jobs. It has a monocentric pattern with a central area of about 200 km² that encompasses Paris city and the neighboring municipalities. The central area accommodates about 3 M people and 2 M jobs. From center to outskirts, urban density declines from 20,000 people per km² down to 1,000 at 30 km from center, passing by 8,000 at 12 km and 4,000 at 20-25 km.

This monocentric urban area is served by high capacity transportation modes (cf. figure 1). The motorway network includes a set of radial roads together with three ring roads, namely "Boulevard Périphérique" around Paris city, "A86" around the central area and "A104" at about 25 km from center. Even more important, the transit network includes 14 metro lines radial or ring-shaped with respect to city center, plus five radial lines of so-called RER for express rail lines, plus 9 regional rail lines called "Transilien". At the 2030-2035 time horizon, five new lines of heavy automated metro will bring about 200 km of ring routes, giving rise to full-fledged "Grand Paris Express" network.

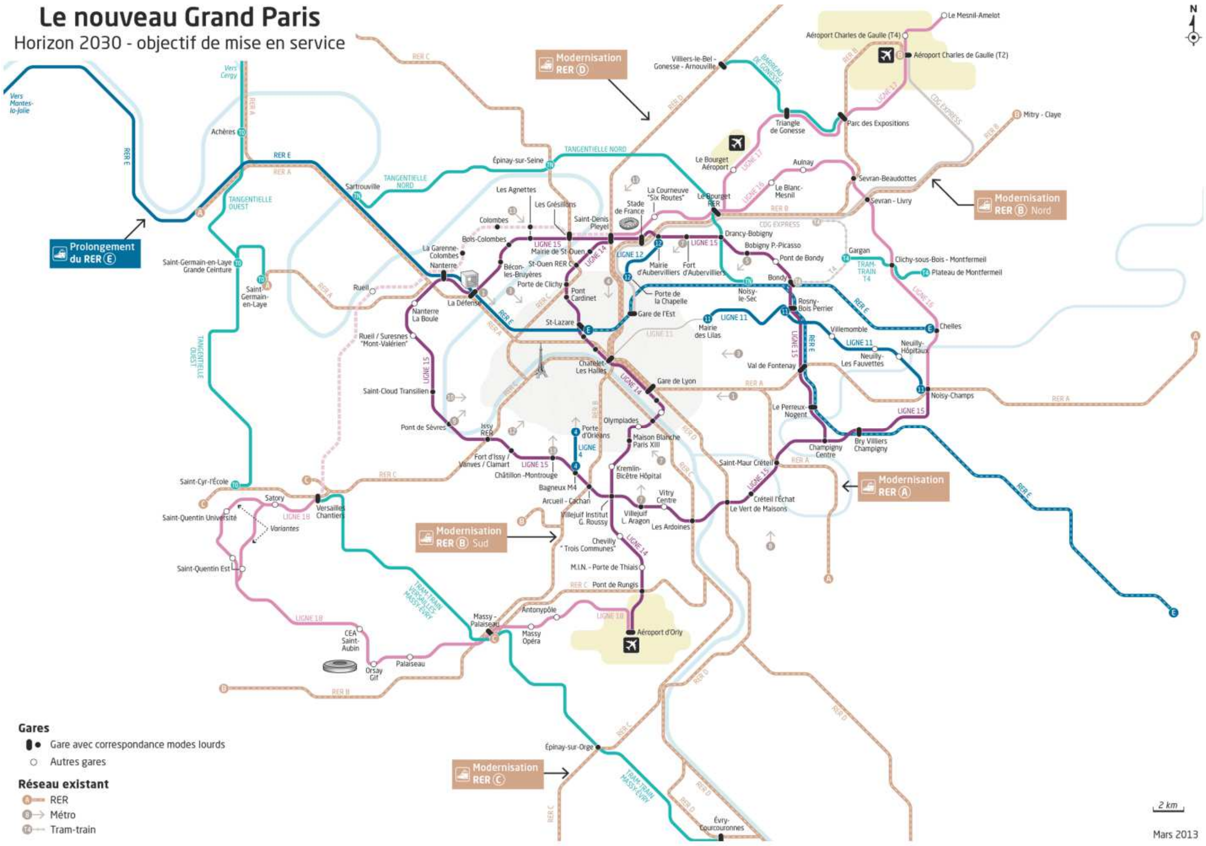

Fig. 1. Paris metropolitan area and its rail network including additional GPE lines (RF, 2015).

2.2 St Denis area

"St Denis" lies on the northern fringe of the central area, halfway between the Boulevard Périphérique and A86 ring motorways. It is the third most populated municipality of the Paris metropolitan area. Adjacent to and located north of Paris city, Saint-Denis has recently experienced a strong economic development, with the establishment of several national and international firms and headquarters. Saint Denis also plays a key role on the French sport scene with the presence of the national football and rugby stadium, the Stade de France.

A combination of factors accounts for the recent development of Saint-Denis: a good accessibility by public and private transport, the availability of office floor space and of vacant land, and low real estate prices compared to Paris city or the business district of La Défense. Economic stakeholders also anticipate the arrival of the Grand Paris Express (GPE) network. Indeed, the Saint-Denis Pleyel station will be a major multimodal hub that will connect four of the five new automated metro lines, as well as the existing heavy rail line RER D and metro line 13. Accordingly, an average number of 250,000 users per day is expected when the station is fully operational.[2] The Grand Paris Express network will further improve the accessibility of Saint Denis, in particular toward Paris city and the Charles de Gaulle international airport. This, combined to the presence of the Stade de France, has led the French Olympic committee to choose Saint-Denis as the main site for the Olympic Village were France to host the 2024 Olympic Games.

[2] https://www.societedugrandparis.fr/gare/saint-denis-pleyel#elements-cles-saint-denis-pleyel

2.3 Study area

Our study area consists of a 2.5 km disk centered on the Saint-Denis Pleyel station. It overlaps five municipalities: Saint-Denis, L'Île-Saint-Denis, Saint-Ouen, Aubervilliers, and the 18th district of Paris city. Overall, the study area accounts for 1.5% of regional population against 2.5% of regional employment (see Table 1), reflecting the economic attractiveness of the zone. Regarding the public transport supply, the study area enjoys a very good regional accessibility thanks to the combination of two heavy rail RER lines, one metro line, and after the opening of the GPE of four additional automated metro lines. On the other hand, local accessibility is not on par with the regional accessibility. Currently, the main stations can be accessed using bus feeder lines, which suffer from low service quality (be it in commercial speed or frequency). This disparity between an excellent regional accessibility and a low local accessibility might hinder the full development of Saint Denis in regard to its economic potential.

Tab. 1. Demographic and socioeconomic features of the study area compared to Paris region, as of 2015.

	Study Area	Paris region ("Ile-de-France")
Population	167 274	11 452 074
Employment	133 435	5 383 506
Area (km²)	18	12 030
P+E density (/km²)	16 706	1399
# of Traffic Analysis Zones	14	1289

2.4 Spidernet design to serve the St Denis study area

Geographic databases with utmost disaggregation about land-use, buildings, infrastructure networks, are available from the French national institute for geographic information (IGN's "BD Topo" database). By careful visual inspection, we drew a PRT network centered on the St Denis Pleyel place with dedicated ways stretched to serve demand hotspots. 48 access stations were located so as to deliver good spatial accessibility along the lines, with special emphasis put on connectivity to the existing public transit network.

As for urban integration, it was assumed that the PRT mainline infrastructure is made of elevated beams containing rail, intended for the circulation of suspended podcars (Fig. 3).

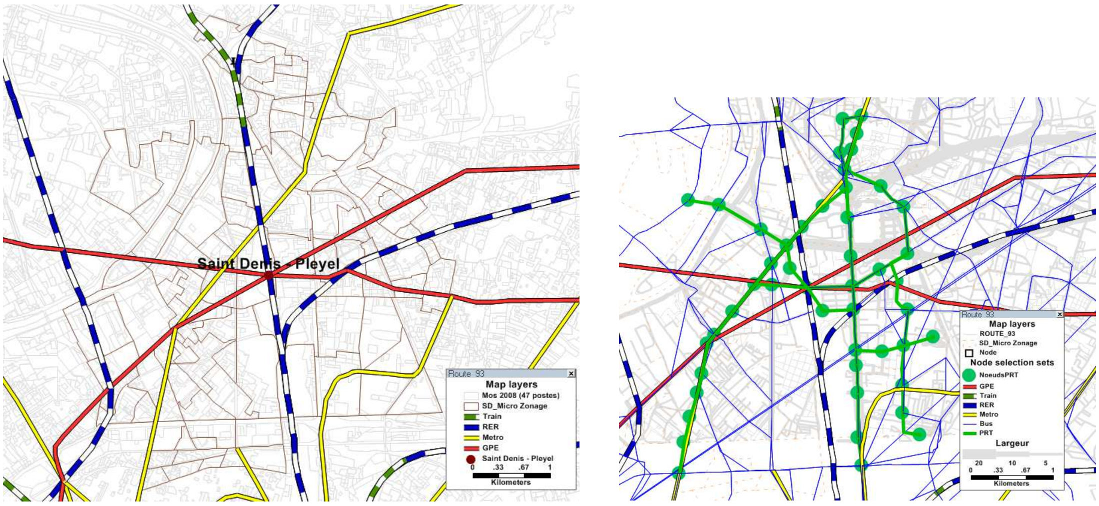

Fig.2. (a) Study area, (b) PRT network.

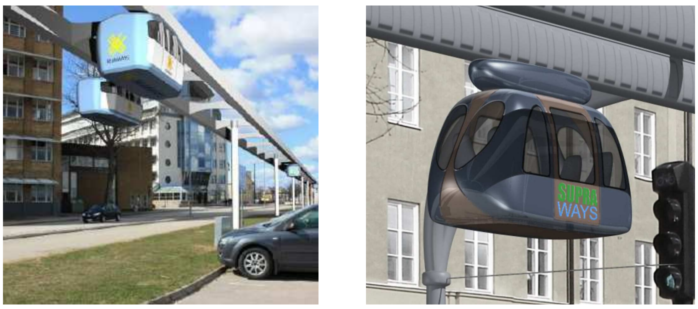

Fig. 3. (a) Elevated dedicated way (source I. Andreasson), (b) Podcar (source Beamway).

Such design is purported for easy implementation along and above large roadways or ground-level railways. The remaining issues pertain to (i) junctions between PRT lines, (ii) off-grade crossings between such lines or with other obstacles, (iii) station design and local integration.

3. SIMULATION OF SPIDERNET DEMAND AND TRAFFIC

Let us now move to demand and traffic simulation of the PRT network designed for the St Denis area. After introducing the regional Travel Demand Model (subsection 3.1), we indicate some set-ups specific for PRT modeling (subsection 3.2). Then, we report on simulation outcomes in terms of passenger traffic, modal split, spatial structure of trip flows (subsection 3.3). Next, a sensitivity analysis is performed with respect to fare (subsection 3.4). Lastly, a tentative assessment of revenues, costs and financial profitability is sketched out (subsection 3.5).

3.1 The regional Travel Demand Model (TDM) "MODUS"

We used the 4-step travel demand model called MODUS developed by the State Planning Agency of the Paris region (DRIEA). This model is purported to study planning schemes for the two transportation networks that exert structuring effects onto the urban area: the roadway network and the transit network that includes bus lines as well as train-based services.

The MODUS model involves the following sequence of 5 steps, among which the traditional 4 ones:

1. **Trip generation:** The regional area is divided into about 1,300 Traffic Analysis Zones (TAZ). Eight kinds of person activity are distinguished: Home, Work, Study, Professional matter, Private matter, Shopping, Personal, Other. Each kind makes a specific purpose of travel, for which the daily emissions / receptions of trips at the zone level are modeled on the basis of land-use factors (i.e. number of people / jobs of such or such type). These trip flows either emitted or received constitute the generated demand. A further distinction is made between trip-makers depending on whether they have easy personal access to private car or not.
2. **Trip distribution:** by pair of origin-destination activity kinds, a doubly-constrained gravity model distributes the associated trip flows among the origin-destination zone pairs.
3. **Time of day split:** again by trip purpose and private car status, and by origin-destination pair, the daily trip flows are split between successive time periods over the day on the basis of period multimodal quality.
4. **Mode choice:** again by trip purpose, private car status and origin-destination pair, and by time period, the period multimodal trip flow is split between three modes of transportation, namely (i) private car (including motorcycles), (ii) transit, (iii) active modes (walking, bike). A multinomial logit model of discrete choice between the three options is used to model behavioral choice: to each option is associated a "utility function" that depends on option's characteristics together with traveler's features. The behavioral principle is that of individual economic rationality: assumedly, the option yielding maximum utility to the individual decision-maker is chosen (up to a random disturbance).
5. **Network assignment:** by time period and travel mode, the trip flow of each origin-destination pair is assigned to the shortest path(s) according to a function of path generalized cost (i.e. a cost to the individual trip-maker, including the out-of-money cost, the value of time spent, that of comfort experienced etc). This applies to the roadway network, after derivation of the car trip flows from the passenger trip flows through a division by an average occupancy factor of cars by trip-makers. This applies also to the transit network. Then, the path trip flows, obtained from the path assignment of the origin-destination trips, are aggregated by network link: the resulting link flows induce the effective traffic conditions, primarily car travel time on the roadway network and on-board comfort and wait time on the transit network. This dependency of local conditions onto trip flows is a feedback effect with respect to the dependency of path assignment onto local conditions. This is why the resulting state is called an equilibrium.

Traffic assignment onto a modal network determines the effective quality of service by origin-destination pair for that period. The associated generalized cost is taken back to previous steps dealing with mode choice and trip distribution, so as to establish a multistage traffic equilibrium.

3.2 Specific model set-ups to deal with PRT supply and demand

On the supply side, a PRT mode is modelled by splitting the dedicated ways into a set of oriented routes: every oriented route with its sequence of stations is modelled as a transit route. The route-based transit service is given infinite nominal frequency, whereas transfer times between the oriented routes are set to zero, in order to mimic uninterrupted point to point service between every station pair. The run time of each link (part of route stretched between successive junctions) is set according to its distance and the postulated commercial speed (hereby set to

50 km/h). Conversely, the wait time for a traveller to get a podcar is modelled by associating specific transfer time to every "turning movement" to the PRT link from the previous link of another mode, on the basis of that previous mode: 3 min from underground transit (train, metro and RER), 2' from ground transit mode (bus or tramway) and 1 min from walk mode. These times include a nominal wait time in addition to the pedestrian time for physical transfer. Egress times from PRT to next mode are set up accordingly.

In the utility function of a passenger, walk time and wait time are each penalized by a specific factor of about 2, with reference to run time spent on-board and seated. A value of time of 12 €/h is taken for transit run time. The resulting time costs are added to the trip fare.

Another key model set-up was to refine the Traffic Analysis Zones (TAZ). In the original MODUS model, our study area only consists of 14 TAZs, with a mean area of 1km². Because the PRT is to serve as a last-mile mobility solution, zones must be smaller to correctly capture demand utility and travel behaviour. Accordingly, the 14 original TAZs were subdivided into 88 micro-TAZs by considering the existing blocks, land-use characteristics and development projects in the area. Population and employment data were collected at the finest possible scale, and disaggregated when necessary at the micro-TAZ scale based on local land-use patterns.

In addition to a reference scenario of transit supply without Spidernet (s0), we defined a set of four scenarios including Spidernet and differentiated by its pricing, at respectively (s1) 0 €/km meaning that the holders of transit subscription cards can take Spidernet for free, (s2) 0.25 €/km, (s3) 0.5 €/km, (s4) 1 €/km. In all scenarios, apart from Spidernet, a 2030 state is taken for transit supply, thus adding the new GPE lines to the 2015 state. On the demand side, the above-mentioned utility functions were estimated as of a 2015 state. The demand flows by trip purpose, time period and origin-destination pair also refer to that state. Overall, the state of supply and demand is a notional one, associating future transit supply with past reference demand.

3.3 TDM simulation outcomes

Let us now introduce the results of traffic simulation for scenario (s1) of "PRT for free to transit card-holders" as opposed to scenario (s0) "Transit network including GPE but no PRT". For further discussion, the indicators pertaining to alternative pricing scenarios (s2-4) are also displayed in the figures and tables that follow.

First, the effect of Spidernet around St Denis on the quality of service of the regional transit network is remarkable: Table 2 indicates an additional 38,000 transit trips per day, meaning +0.4% of the total number of trips in a powerful transit network that involves a large set of heavy rail lines as well as numerous bus lines. The effect on the modal share of transit at the regional level is +1‰, which suggests that such local Spidernets around 80 GPE stations could bring +8% of modal share to transit modes (now at 22%), thus accomplishing a major transition.

Second, at the local level the Spidernet accommodates large flows: at morning peak hour, about 26 thousand users travel some 69 thousand km (see Tables 3 and 4). Hence the average trip leg distance amounts to 2.6 km. As there are 39.2 km of dedicated ways (=2 x 19.6), the average passenger load amounts to 1,760 pphpd – much in excess of the way capacity estimated at 1,200 cars/hour (assuming 3 s minimal headway as safety margin), so that it would be feasible only by use of car-sharing. At the local scale PRT flows are massive among ground or above-ground transit flows (see Fig. 4a). However, they remain modest at the regional scale – due to the long transit legs by heavy rail lines (see Table 3).

Tab. 2: Modal split under different situations (residents' trips per working day in Paris region as of 2015).

	s0		s1		s2		s3		s4	
Travel mode	Flow (1000s)	Share	Flow (1000s)	Share	Flow (1000s)	Share	Flow (1000s)	Share	Flow (1000s)	Share
Private cars	13 137	35,6%	13 117	35,5%	13 125	35,5%	13 129	35,5%	13 130	35,5%
Public transport	8 590	23,3%	8 628	23,4%	8 612	23,3%	8 606	23,3%	8 602	23,3%
Active modes	15 211	41,2%	15 193	41,1%	15 200	41,2%	15 203	41,2%	15 205	41,2%
All modes	36 938		36 938		36 938		36 938		36 938	

Tab. 3. Passenger traffic (thousand passenger.kilometers) by main transit mode at morning peak in Paris region.

	s0	s1	s2	s3	s4
Train	4 280	4 280	4 281	4 283	4 282
RER	5 937	5 943	5 932	5 930	5 931
Metro	6 159	6 172	6 185	6 183	6 182
Tramway	225	220	220	222	223
Bus	2 850	2 841	2 833	2 835	2 838
PRT		69	39	25	10
Total	19 451	19 526	19 489	19 477	19 467

Tab. 4. PRT users at morning peak hour.

	s1		s2		s3		s4	
	PRT Users	Share	PRT Users	Share	PRT Users	Share	PRT Users	Share
Within the study area	2 631	9,9%	2 181	11,8%	1 789	13,5%	1 054	15,9%
Study area - Outside	7 900	29,6%	5 308	28,7%	3 471	26,3%	1 622	24,5%
Outside - Study area	14 853	55,7%	10 898	58,9%	7 953	60,2%	3 955	59,6%
Transit	1 297	4,9%	111	0,6%	3	0,0%	-	0,0%
Total	26 680		18 498		13 216		6 631	

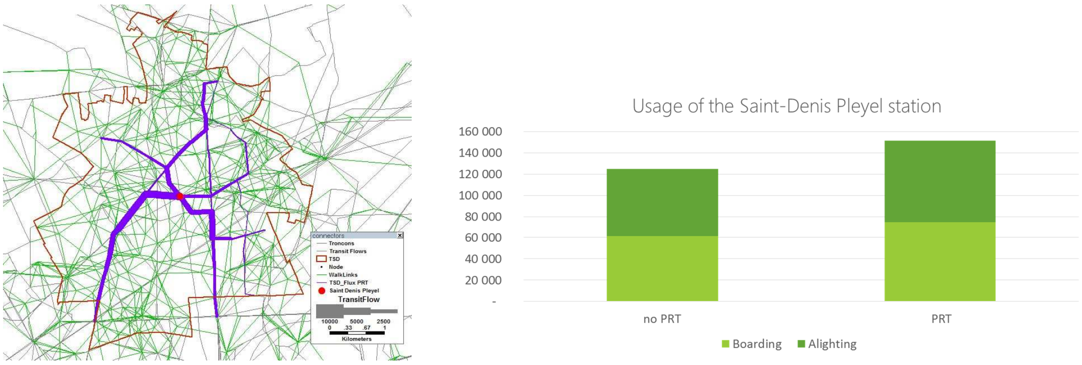

Fig. 4. (a) Passenger trip flows at peak hour, (b) St Denis Pleyel GPE station access and exit flows, per day basis.

Third, the spatial pattern of PRT flows reveals that it is especially attractive along the South-North axis, between St Denis and Paris city passing by “St Ouen” city (Fig. 4a). The number of passengers accessing or egressing the St Denis Pleyel station daily would increase by 20% (Fig. 4b). Further geographical analysis of PRT trips by origin-destination type either internal to study area, or from that area to outside, or from outside to area, or in transit, yields respective shares of about 10% / 30% / 55% / 5%, in line with time period and the large excess of jobs on active population in the study area (see Table 4).

Fourth, about the modal split: at the regional level, Spidernet would attract passenger traffic to the transit network from both private cars and active modes, in roughly balanced amounts (see Table 2). At the local level the preliminary analysis of travelled distances by transit mode indicates that PRT-attracted trips would add traffic to heavy rail modes (yet in modest amount) and subtract traffic from ground transit modes (bus and tramway): see Table 3. However, these assignments to the transit network did not include the trips that would be diverted from private cars and active modes: the related travelled distances still need to be calculated in order to assess the likely complementariness between Spidernet and heavy rail lines.

3.4 The price sensitivity of Spidernet demand

The same initial status applies to all results but modal split on daily basis. As for price sensitivity, as could be expected, increasing PRT fares leads to reducing its patronage and the related traffic effects – be they modal diversion to transit (see Table 2) or within-transit traffic diversion between sub-modes (see Table 3). The spatial pattern of PRT trips is more strongly affected since internal flows and access flows (from outside to study area) get increased shares whereas that of egress is decreased and so is that of through traffic, up to vanishing under scenario (s4) (see Table 5).

Tab. 5. Fare revenues in different situations at morning peak hour.

Scenario	Fare (€/km)	Pax (1000s)	Revenue (€/h)
s1	-	69	-
s2	0,25	39	9 715
s3	0,5	25	12 611
s4	1,0	10	10 323

3.5 Towards cost-benefit analysis

As a teaser for financial cost-benefit assessment, the fare revenues of Spidernet were analyzed: the maximum revenue is attained at fare between .25 and 1.0 €/km (the revenue attained at .5 €/km may be improved upon under another intermediate fare). Yet, this analysis was performed without the trips diverted from non-transit modes, which would yield additional revenue. The provisional value of 12,600 €/h would yield yearly revenues of 21 M€ on postulating that one working day is equivalent to 6 peak hours and one year amounts to 280 working days.

Related costs can be evaluated very crudely based on quantities and unit costs estimates. As for capital investment:

- 20 km of dedicated ways x 5 M€ each = 100 M€,
- 48 stations x 2 M€ each = 96 M€,
- 600 podcars x 50,000 € each = 30 M€.

The fleet size was estimated as follows: at peak hour, under (s3) 25 thousand passenger.km travelled at 50 km/h require about 500 h of podcars; a 20% margin is taken to account for vehicle re-dispatching (15%) as well as maintenance (5%).

Assuming respective lifetimes of 20 years for way and associated infrastructure, 25 years for stations and 5 year for podcars under high duty, the system resources would require capital expenditure with annual amount of

100 / 20 + 96 / 25 + 30 / 5 = 5 + 4 + 6 = 16 M€.

This evaluation neglects interest rates; it is subject to much uncertainty owing to all of its parameters – for instance different lifetimes. For instance, doubling the values postulated for lifetimes would cut the annual capital expenditure by a factor of 2.

As for operations expenditure, on an annual basis, let us include:

- Cleaning, at 2h per station and per day and ½ h per podcar and per day, at 25 €/h: 365 days x (48x2+600/2) x 25 = 1 M€/year.
- Energy: per vehicle and per day, 6 h x 50 km/h x .2 kWh/km = 60 kWh, plus station lighting at 24 h x 1 kW, all at .15 €/kWh along 365 days yields about 1 M€/year.
- System regulation and management: assume 4 staff members for regulation on a 24/7 time basis, 2 agents for maintenance during 8 hours per day and 2 managers on 8 h/day, with hourly wages of 50, 50 and 80 € respectively: this would amount to 1.6 M€/year.

Altogether yielding a rough approximation of 4.4 M€ as for expenditure on operations.

Furthermore, added value tax on ticketing would reduce the net revenues by 5% or 20%, depending on whether the service would be classified as basic or ordinary economic good.

To sum up, capital plus operations expenditure could amount to some 20.4 M€ per year. Fare revenues at .5€/km could yield 21 M€/year, or 16-20 M€ net of tax.

This is prior to cost minimization as well as to revenue maximization. Revenues are estimated on the basis of initial demand forecasts that need be confirmed. However, it appears that costs and revenues could be balanced – indeed a remarkable peculiarity in urban passenger transit.

4. MODAL OPERATIONS AND FLEET SIZING

Let us now focus on both trip serving and modal operations in a much finer way, by using a specific, microscopic traffic simulation model that identifies each individual passenger and each individual car. Our objectives are to assess the feasibility of the claimed quality of service under peak demand, to estimate the fleet size that is required for that, and also to check the traffic capacity of the designed infrastructure. To make the test more powerful in this last respect, we postulate maximum demand, which pertains to the free fare scenario (s1).

4.1 The PRTSim microsimulation model

PRTSim is a traffic micro-simulator for both passenger traffic and car traffic in a PRT system. It deals with passengers on an individual basis, from access station to egress station, with alternative settings about their prior grouping (i.e. family, relations or colleagues) and their acceptance to share cars. Passenger queuing at access station is modelled explicitly, yielding more realistic wait times. Ticketing operations can be modelled, too. Passenger trips are generated by Monte-Carlo random simulation on the basis of origin-destination trip flows derived from the travel demand model.

On the supply side, station platforms are modelled individually, with specific ramp way for access to main network. Each car is modelled individually, with attention to its instantaneous state – whether on station dwelling, waiting, or running along main way. Car driving is automated, with different settings for system management, from central regulation of car driving to decentralized autonomous driving. Central regulation deals with not only passenger carrying but also with vehicle dispatching, assignment to passengers and eventual car-sharing, empty returns… Elaborate management policies can be tailored: the specific policy, together with the maximum wait time tolerable for passenger access, determines the number of vehicles required to serve the demand, hence fleet sizing under peak conditions (but notwithstanding maintenance requirements).

4.2 Microsimulation settings for Spidernet

Using a finer simulation model calls for finer design and specification. On the supply side, we detailed an additional 6.4 km of track way for station platform and ramp access to main way. Off-line stations of three parallel docks were designed, with joint access to main way. Two such stations were twinned to serve the St Denis rail hub. A six-seat capacity was specified for podcars. To improve system performance, several control strategies are combined: a vehicle waits for passengers at the station and departs when 4 seats out of 6 are taken or after 1 minute since the first order, whichever occurred first. Ride-sharing strategy is applied at departure for the same destination. Passengers with different destinations may be carried in one vehicle, under a maximum detour of +20% of the initial travel time as tolerance for every passenger. Vehicle pair coupling strategy is applied in stations.

So, on the demand side, car-sharing is allowed between passengers. Early car reservation is enabled up to 4 min of passenger arrival at station.

4.3 Microsimulation outcomes

Fig. 5 depicts an instantaneous traffic state of the St Denis system at morning peak period. It shows many cars, with dense loading of most Spidernet links.

Table 6 gives the system's performance at morning peak hour with the combination of all ride-sharing and coupling strategies. It comes out that 59% of trips are suitable for matching in the Spidernet network, yielding average vehicle load of 3.6 passengers, and 26% of full cars trips. Fleet utilization is optimized with 84% of vehicles' travelled distances on carrying passengers. The system could accommodate up to 1,850 vehicles and 6,900 passengers per hour and per direction on the most trafficked PRT link. Notice that the regulation policy of 3s safety margin between successive vehicles was adapted for paired vehicles constituting a platoon. This enabled to increase the car flow rate on the most critical link.

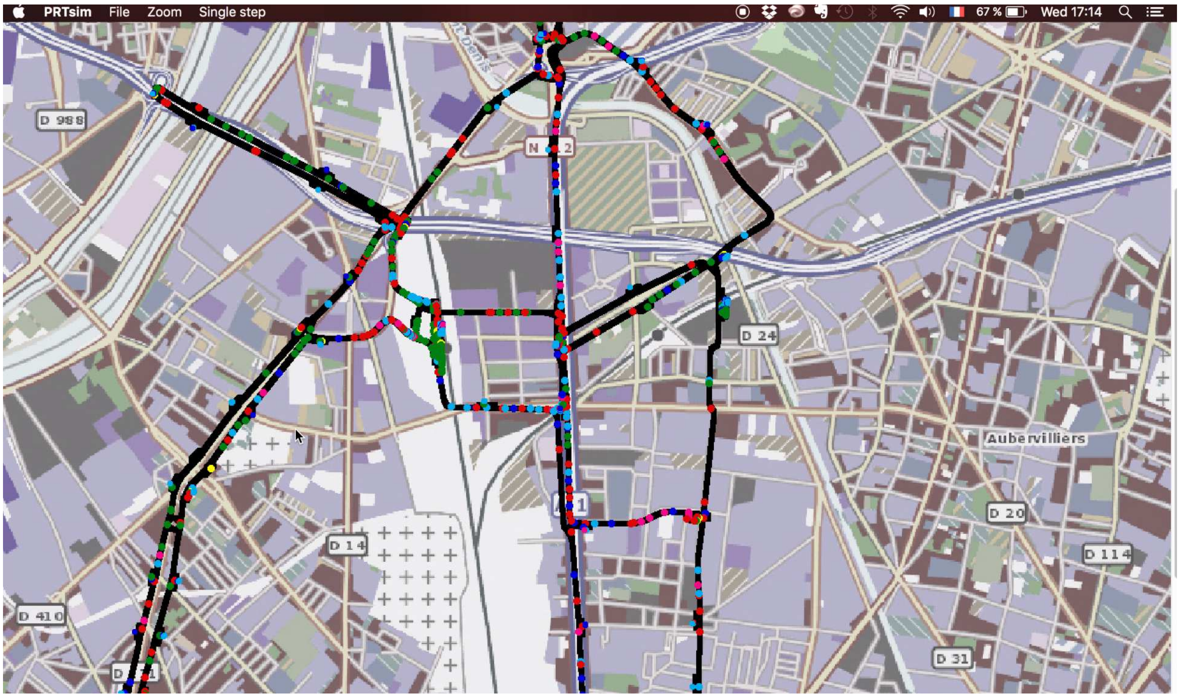

Fig. 5. Instant image of St Denis Spidernet traffic (screen capture from PRTSim).

Tab. 6. Microsimulation results under scenario 1 at morning peak hour.

Vehicle fleet	900
Passenger trips	23 906
Passengers matched	59%
Average load per car of 6 seats	3.6 of 6
Departure for 2 or 3 stops	18+6%
Extra stops per passenger trip	0.21
Average (99%, max) wait time	1.0 (3.2, 5.3) minutes
Average ride time including stops	4.8 minutes
Maximum vehicle link flow	1 850 vehicles/h
Maximum passenger link flow	6 900 passengers/h
Fleet running with passengers	84%

Concerning service quality, PRT users experience wait time of 1 min on average, with 99% of trips waiting less than 3.2 min. Only 21% of travelers made an extra stop en route to drop off or pick up passengers. As for vehicle congestion on the dedicated ways, it takes a maximum value of 18 seconds on the most critical link in that respect.

4.4 Comments

The St Denis Spidernet would operate at almost full infrastructure capacity at peak period and also with more than half-filled cars of six-seat capacity. Such intense use of both infrastructure and vehicles, together with vehicle sharing, demonstrates that, indeed, the Spidernet is a true mode of urban passenger transit.

A system-optimization policy was assumed in our simulation: both on the supply side of system operations and on the demand side with maximum trip matrix under free fare (i.e. no special fee in addition to general transit network subscription).

This leads to estimate fleet size larger than in our prior, TDM-based estimation for cost-benefit assessment (see Section 3.5). However the assumption of a 500-vehicle fleet is adapted to a demand matrix estimated under specific PRT fare of .5 €/km.

As concerns methodology, the application of microsimulation demonstrates the roughness of our first estimation of fleet size, on the sole basis of passengers' travelled distances, commercial speed and 15% margin for empty returns. The resulting 500 cars with individual riding must be compared to 900 cars carrying almost 4 persons per trip on average: the ratio of microsimulation estimation to TDM-based estimation amounts to 7 or 8 (based on 900 x 4 /500). The underlying factors include the time needed by cars for station dwelling and holding. The car-sharing policy is likely to exert some effect, yet limited to 20% since this is the average surplus of travelled distance per individual passenger.

5. CONCLUSION

The case study of St Denis Spidernet, primarily purported for connection to the Grand Paris Express rail network, suggests that "demand deposits" do exist for improved accessibility to rail stations granting access to the metropolitan area. A sketch cost-benefit assessment suggests that the PRT solution could achieve financial balance of costs and commercial revenues, under a fare level of .5 €/km.

Beyond the particular case study, we have built a comprehensive methodology to assess both the demand potential and the modal operations of a Spidernet. We used a Travel Demand Model to estimate the potential demand and its sensitivity to service fare: indeed, such a model is required to capture the territorial features and to evaluate the relevance of a specific solution. Microsimulation is in order, too: it enabled us to refine system specification, to assess traffic performance and the resulting quality of service under effective conditions rather than nominal. Key outcomes of microsimulation include fleet sizing, with satisfactory relevance; as well as car-sharing potential.

Much research remains to be done. First of all, our objective of assessing Spidernet passenger traffic and the related additional rail passenger traffic has been partially satisfied only: the trips that would be diverted from the private vehicle and active modes still need to be included in transit assignment to the regional network.

Then, the systemic effects of several Spidernets around different stations in a given metropolitan area still need to be estimated. What would be the total "one-sided" potential of such a set of stations? The important effect of St Denis Spidernet at the level of the metropolitan area is likely to be exception rather than average. What would be the "two-sided" effect for origin-destination pairs that would use Spidernets both for access to and egress from the heavy rail network?

Next, specific behavioural surveys are required to assess Spidernet demand and its price sensitivity in a more naturalistic way.

Lastly, on the supply side there are two large avenues for further research:

- About the urban integration of elevated ways and, above all, PRT stations: specific architectural design is required there, taking into account geometric constraints, local urbanization and legal requirements.
- About the modal "production function": from technology to cost-setting, much investigation is required. What design and implementation for stations? What materials and mechanical structure would be convenient yet economical for elevated ways and their supporting pillars? What construction processes whether on-field or in-factory? These issues are crucial to achieve industrial efficiency and yield economies of scale. The same stakes pertain to podcar design, construction and maintenance, too.

ACKNOWLEDGEMENTS

This research was supported by the Research and Education Chair on "the Socio-economics and Modeling of urban transit", operated by Ecole des Ponts ParisTech (ENPC) in partnership with the Transport Organizing Authority in the Paris Region (STIF), to which the authors are grateful. We thank the DRIEA (regional and inter-departmental direction of equipment and planning in Ile-de-France) which provided the network data and travel demand model MODUS. We are also indebted to Prof. Ingmar Andreasson for his wise advice and kind guidance, and to Mr. Claude Escala (Supraways) for stimulating discussions.

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